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Environmental Effects of Dredging Technical Notes

EQUIPMENT MOBILITY IN CONFINED DREDGED MATERIAL DISPOSAL AREAS; FIELD EVALUATIONS

PURPOSE: This technical note describes recently completed equipment evaluations and presents data on mobility of this equipment in confined dredged material containment areas. The equipment evaluation included newly developed four- and six-wheeled low-ground-pressure vehicles. This equipment is typically used to tow a rotary ditching device to create surface trenches to enhance drainage and dewatering of confined dredged material disposal sites.

BACKGROUND: Studies were conducted during the Dredged Material Research Program (DMRP) (1973-1977) to identify and evaluate various pieces of low-ground-pressure construction equipment for use in dredged material containment areas. Procedures were developed (by modification of the existing NATO Reference Mobility Model (NRMM) and subsequent Army Mobility Model (AMM)) to predict the performance of this equipment for conducting various work functions (Green 1977, Willoughby 1977, 1978). Since completion of the DMRP, new equipment which can be used to trench the surface of dredged material containment areas has become available. The newly developed low-ground-pressure equipment is being used or is being considered for use by several Corps of Engineer (CE) Districts to conduct trenching operations in confined dredged material disposal areas. A number of questions have been raised regarding performance of this equipment and comparison of its performance to other available equipment. These recent studies were conducted to evaluate the performance of this newly developed low-ground-pressure equipment on soft soils in dredged material containment areas.

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Introduction

Confined dredged material disposal sites are typically managed to enhance their volumetric storage capacity. To meet this objective, water must

be removed from the area. For storage capacity considerations, both surface and interstitial water must be removed from the site to allow evaporative drying and subsequent reduction in required storage volume for the dredged material. The most cost-effective management practices used to achieve these goals include creation of a smooth, gently sloping dredged material surface by careful selection of dredge discharge points, periodic lowering of the weir crest elevation to allow continued drainage, surface trenching to facilitate movement of water to the outflow structure, and removal of dried surface material from within the site (Palermo, Montgomery, and Poindexter 1978; Headquarters, US Army Corps of Engineers 1986).

During implementation of the management activities at any dredged material disposal site, numerous tasks are undertaken inside the disposal area. Most of these tasks require mobility within the site for such activities as surveying and reconnaissance, trenching, and earthmoving. To assist in these tasks, several types of equipment are routinely used in CE disposal facilities, but most of the equipment is limited in its performance. Some equipment is amphibious and can be used in the sites only when the dredged material is in a fluid state. Other equipment can begin operations in the sites at various stages of dredged material drying (after some amount of crust has formed). The major problem is that there is a period of time between the fluid stage and the formation of sufficient crust during which none of the presently available equipment is mobile in the disposal sites. There is a need for equipment capable of performing work functions during this critical period of time when trenching operations and other activities need to begin or continue.

Low-ground-pressure rubber-tired vehicles have been recently introduced which may facilitate operations within disposal areas. Because of the interest of various CE Districts in the newly developed vehicles and because of claims by manufacturers that this equipment can operate in all environments from fluid to solid, the US Army Engineer Waterways Experiment Station (WES) conducted field evaluations of the equipment in use in several CE Districts. Evaluations were conducted in Mobile, Norfolk, Philadelphia, and Savannah Districts. In the Mobile District, an ARDCO six-wheeled vehicle was evaluated, while a GEMCO four-wheeled vehicle was tested in the other three Districts.

Equipment Evaluation Procedures

During field evaluations, data on the equipment, the equipment operation and performance, and the soils were collected. Pertinent data on the equipment included weight, horsepower, number of tires, and vehicle ground contact pressure. Operation and performance data included speed of movement across the disposal site, linear feet of ditching accomplished per hour, and size of the trench formed (which indicates rate of production in quantity of material removed per hour). Soils data collected included soil strength as recorded by the hand-held cone penetrometer, shown in operation in Figure 1. Results of the field evaluations are discussed in following sections.

To evaluate the potential for equipment mobility in a dredged material disposal site, field data on soil strength must be collected. These data included the cone index (CI) and remolding index (RI), from which the rating

Figure 1. Field soil testing for vehicle mobility determination using the cone penetrometer

cone index (RCI) is calculated. The RCI gives an indication of the strength of the soil. The vehicle data is used to calculate a vehicle cone index (VCI), which indicates soil strength required to support the vehicle. Two values of VCI are usually determined: VCI_1 for reconnaissance operations (one pass of the equipment over an area) and VCI_{50} for trenching and earthmoving (multiple passes of the equipment over a particular area). By comparing the actual soil strength (as reflected in the RCI) to the soil strength required to support the vehicle (as reflected in the VCI), one can determine whether the vehicle can operate within a given disposal site. The operation and performance data can be used to determine the productivity of the trenching operation. This allows direct comparison of various pieces of equipment when operated under the same field conditions. In the following paragraphs the results from the field evaluations are presented for each field site and comparisons are made among field sites.

Definitions

The following definitions as presented by Willoughby (1977) are provided to assist the reader:

Cone index (CI): index of the shearing resistance of a medium obtained with a cone penetrometer. The value obtained represents the vertical resistance of the medium to penetration at 6 ft/min of a 30-deg cone of 0.5-sq in. base or projected area. The value, although usually considered dimensionless, actually denotes pounds of force on the handle divided by the area of the cone base in square inches (i.e., pounds per square inch).

Critical layer: layer of soil most pertinent to establishing relations between soil strength and vehicle performance. For 50-pass performance in fine-grained soils and poorly drained sands with fines, it is usually the 6- to 12-in. layer; however, it varies with weight and type of vehicle and with soil strength profile. For one-pass performance, it is usually closer to the surface.

Mobility index (MI): dimensionless number used to estimate the vehicle cone index, which results from a consideration of certain vehicle characteristics.

Rating cone index (RCI): product of the remolding index and the average of the measured in situ cone index for the same layer of soil. The index is

valid only for fine-grained soils and poorly drained sands with fines.

Remolding index (RI): ratio that expresses the proportion of original strength of a medium that will be retained after traffic of a moving vehicle. The ratio is determined from CI measurements made before and after remolding a 6-in.-long sample using special apparatus.

Vehicle cone index (VCI): the minimum soil strength in the critical soil layer in terms of RCI for fine-grained soils and CI for coarse-grained soils required for a number of passes of a vehicle, usually 1 or 50 passes. As the values of VCI decrease, the go-no go performance capability of the vehicle increases.

VCI_1: experimentally determined minimum CI or RCI of the critical layer required for a vehicle to complete one pass. The one-pass critical layer for most vehicles is usually the 0- to 6-in. layer, except in dredged material deposits where the critical layer is often the 6- to 12-in. layer.

VCI_{50}: experimentally determined minimum RCI of the critical layer required for a vehicle to complete 50 passes in a fine-grained soil. VCI_{50} is computed for a given vehicle by first calculating an MI from selected vehicle characteristics and then converting the MI to VCI_{50} by means of a curve or table.

Drawbar pull: amount of sustained towing force a self-propelled vehicle can produce at its drawbar under given test conditions.

Mobile District Field Evaluations

Field evaluations were conducted in the Mobile District from May 4-6, 1987. These evaluations were conducted in conjunction with contract trenching operations in the Triple Barrel disposal area in Pascagoula, MS. The site is located just west of Ingalls Shipyard near US Highway 90.

The Triple Barrel disposal site is composed of three separate cells. At the time of field evaluations, only the two western cells were being trenched (shown in Figure 2); the third cell had passed the fluid stage but did not have sufficient surface crust to permit vehicle mobility. Therefore, performance data were collected in only the two western cells. Together, the two western cells measure 1,200 ft wide by 2,400 ft long and are separated by a 4-ft-high cross-dike. Each of the cells has one weir structure for drainage of surface water. The majority of the material in the containment areas is

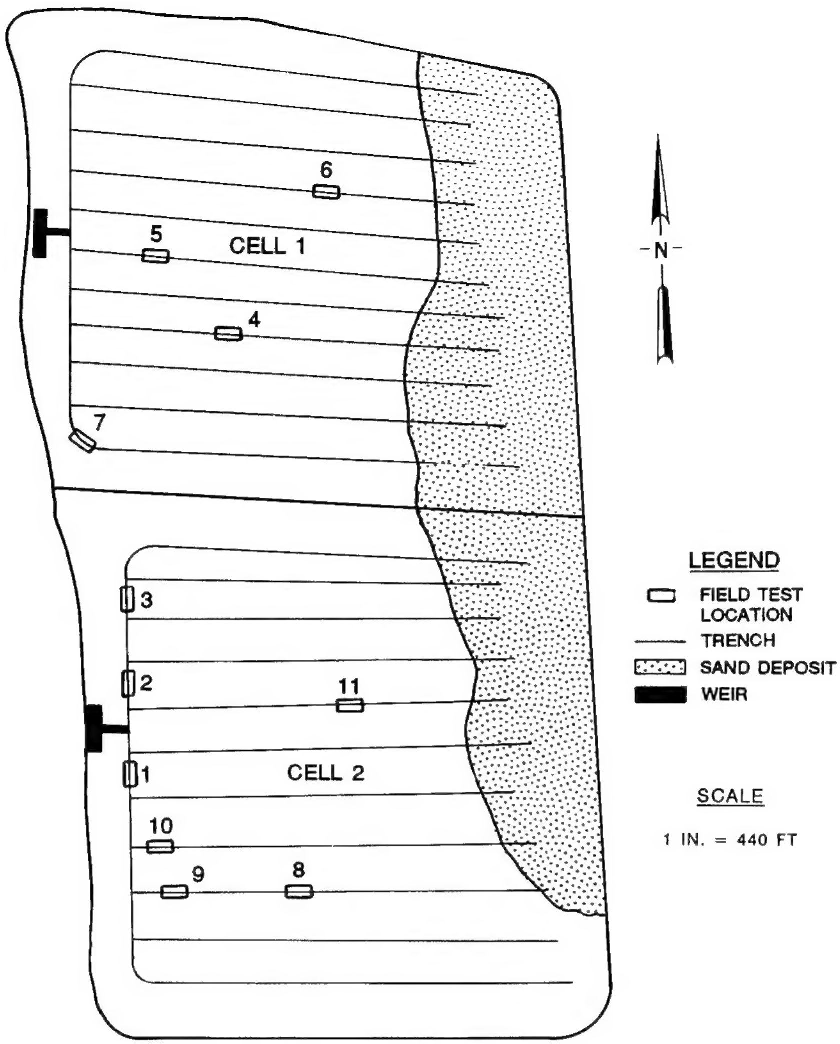

Figure 2. Triple Barrel dredged material disposal site, Pascagoula, MS

sandy clay and silty clay. The thickness of dredged material deposit varies from 8 to 9 ft. Along the eastern dikes of cells 1 and 2 is a large area of sand; the sand extends approximately 100 to 150 ft from the dike into the disposal site. The sand was deposited on the eastern side of the disposal site because that had been the location of the inflow pipeline. The area of sand is shown as the shaded area in Figure 2.

The equipment tested at Triple Barrel was an ARDCO "K" 6x6 rubber-tired vehicle which pulled a Dondi 95 ditcher (shown operating in Figure 3). The equipment is owned and operated by ARDCO of Houston, TX. The ARDCO has 113 hp and weighs 22,100 lb; it has a vehicle ground contact pressure of 1/64 psi. A tracked marsh buggy was kept on standby at the disposal site to pull the ARDCO

Figure 3. Rubber-tired ARDCO vehicle with Dondi ditcher raised between trenching operations in Triple Barrel disposal site

vehicle through soft sections, if necessary. The vehicle cone index (VCI) of this vehicle was determined to be 7 for reconnaissance (one pass of the equipment); the VCI_{50} for multiple passes over the same area was 18.

The surface of the two cells tested had a very thin crust which thickened slightly toward the sand deposit. The surface of cell 1 was almost barren, while cell 2 had a covering of short grasses along with some taller grass. Eleven tests were conducted in the two cells. In the southwest corner of cell 1, the rubber-tired vehicle used at this site created ruts while ditching which were about 6 in. deep; the soil in this location was so soft and wet that the ditch side slopes collapsed. In the southwest corner of cell 2, the vehicle became immobilized and had to be pulled out of the soft area. The soil in the southwest corner was softer and wetter than in the surrounding areas. Throughout most of the area as trenching occurred, water flowed quickly into the trenches, indicating the immediate value of the trenches in dewatering the dredged material.

The data collected at the Triple Barrel disposal site (Table 1)

indicated that the top 6 in. of dredged material was somewhat stiffer than the 6- to 12-in. layer; the 12- to 18-in. layer was intermediate in strength. This indicated that the 6- to 12-in. layer is the critical layer with respect to vehicle mobility. If the equipment were to break through the desiccated crust, it would in effect have to operate on the softer soils. Therefore, it is necessary to evaluate the mobility of the vehicle with respect to this 6- to 12-in. layer.

Since the critical depth for the Triple Barrel disposal site was the 6- to 12-in. depth, comparison of the RCI and the VCI for that layer provides information on the expected mobility within the site of the ARDCO vehicle. The RCI of the 6- to 12-in. layer varies from 6 to 28; the VCI for the ARDCO vehicle is 7 for one pass and 18 for multiple passes. Analysis of these data indicate that the vehicle should be able to make one pass across most of the site, although at two of the testing sites a value of RCI was obtained that was below the required value of 7. Three other testing locations had RCI values that were marginally above the required value, indicating somewhat questionable mobility. These predictions (which were made in this case after the fact) were substantiated by field performance. Across most of the site, the ARDCO was able to make one pass with no problem; in several areas within cells 1 and 2, the vehicle made relatively deep (up to 6 in.) ruts which indicated that the equipment was marginally mobile; and in one location, the vehicle bogged down and had to be pulled out.

Norfolk District Field Evaluations

From June 10-12, 1987, field equipment evaluations were conducted in the Craney Island disposal facility, which is located in Portsmouth, VA, near the confluence of the James and Elizabeth Rivers. This facility encompasses approximately 2,500 acres and is divided into three compartments (Figure 4) so that dredged material disposal can be rotated annually among the cells, allowing two years of drying to occur between disposal operations in each cell. Each cell has two large weir structures on the western side, and material has typically been pumped into the site along the east side. The material in Craney Island is composed of fine-grained silts and clays with some sand; the deposit is approximately 40 ft thick. Since material was being pumped into the south cell and the center cell was still fairly soft, all tests were

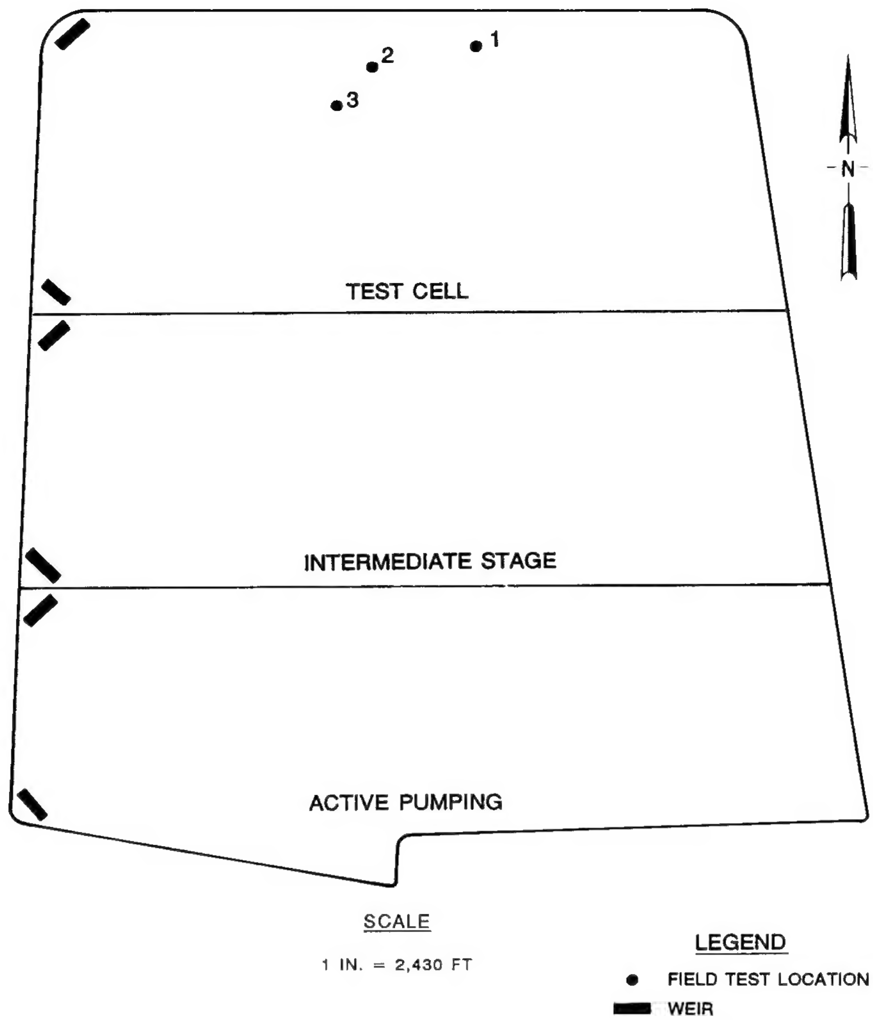

Figure 4. Craney Island dredged material disposal area, Portsmouth, VA

performed in the north cell where trenching operations were being conducted.

The equipment evaluated at Craney Island was a GEMCO GT-150 4x4 rubber-tired vehicle, pulling a Dondi 75 ditcher. This vehicle is owned and operated by the Norfolk District. This GEMCO has 135 hp and weighs 14,440 lb. The vehicle ground contact pressure is 1.6 psi. The vehicle cone index for reconnaissance (VCI_1) for this vehicle was determined to be 7, while the VCI_{50} for multiple passes was 19.

Because management practices had been implemented in the north cell during the previous fiscal year, the surface of the dredged material was dry and significant crust had formed. Therefore, the trenching equipment had no mobility problems except in one or two localized places near the site

perimeter. Only sparse vegetation was present across the Craney Island disposal facility.

Field tests were conducted at three locations in the north cell of Craney Island. During the trenching operations, no flow of water into the trench was observed in most locations throughout the cell. Only in the western end of the site was appreciable water flow into the trench noticed (Figure 5). This occurred, most likely, because material is deposited on the

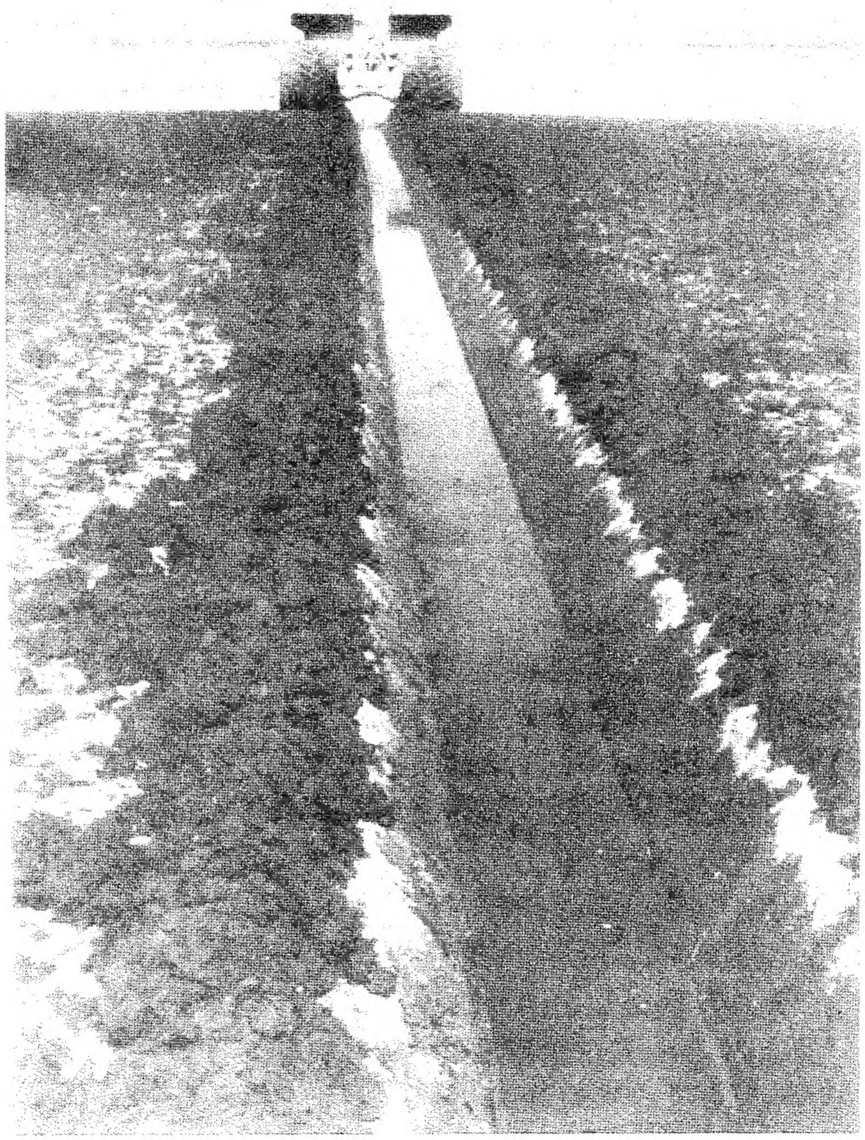

Figure 5. Trench created by GEMCO vehicle with Dondi ditcher at Craney Island; note water which immediately flowed into trench

eastern end, so the western end is at a lower elevation and contains the very fine-grained material which drains very slowly.

The data collected at Craney Island (Table 2) indicated that the dredged material generally increased in strength with depth. This is the situation usually found in regular soil deposits. Therefore, the critical depth for mobility considerations is the 0- to 6-in. layer. Comparison of the VCIs for this vehicle (VCI_1 = 7 and VCI_{50} = 19) with the RCI of the soil for the 0- to 6-in. layer (Table 2) predicted that the vehicle should be able to operate throughout the site, assuming that the test locations were indicative of conditions across the site. Since the vehicle had no mobility problems near the test locations or throughout most of the site, the prediction is considered good.

Philadelphia District Field Evaluations

The Artificial Island disposal area was the location of field equipment evaluations on June 15-17, 1987. The disposal site, located approximately 60 miles southwest of Philadelphia, is compartmentalized into three separate cells by interior dikes. Figure 6 is a map of the Artificial Island site. Each cell has one weir for water drainage. The dredged material in Artificial Island is predominantly sandy clay. No specific information was available on the thickness of the dredged material deposit in this site. All three cells were covered with a thick growth of *Phragmites* which had to be removed by bulldozing before trenching could begin to prevent entanglement of the vegetation in the rotary ditching device (Figure 7).

The equipment used at the Artificial Island site consisted of a GEMCO GT-300 which pulled a Dondi 95 ditcher. The vehicle and ditcher are owned and operated by the Philadelphia District. Vehicle data and performance information are presented in Table 3.

There was no distinguishable surface crust in the Artificial Island site. The entire deposit had dried fairly uniformly, allowing the vehicle to operate without the need for a definite crust. In addition, the roots and stalks of *Phragmites* provided a working mat which provided additional (reserve) support. The roots present throughout the subsurface caused some problems with obtaining cone penetrometer readings. Field evaluations were conducted in six locations within the center cell. In tests 5 and 6, two

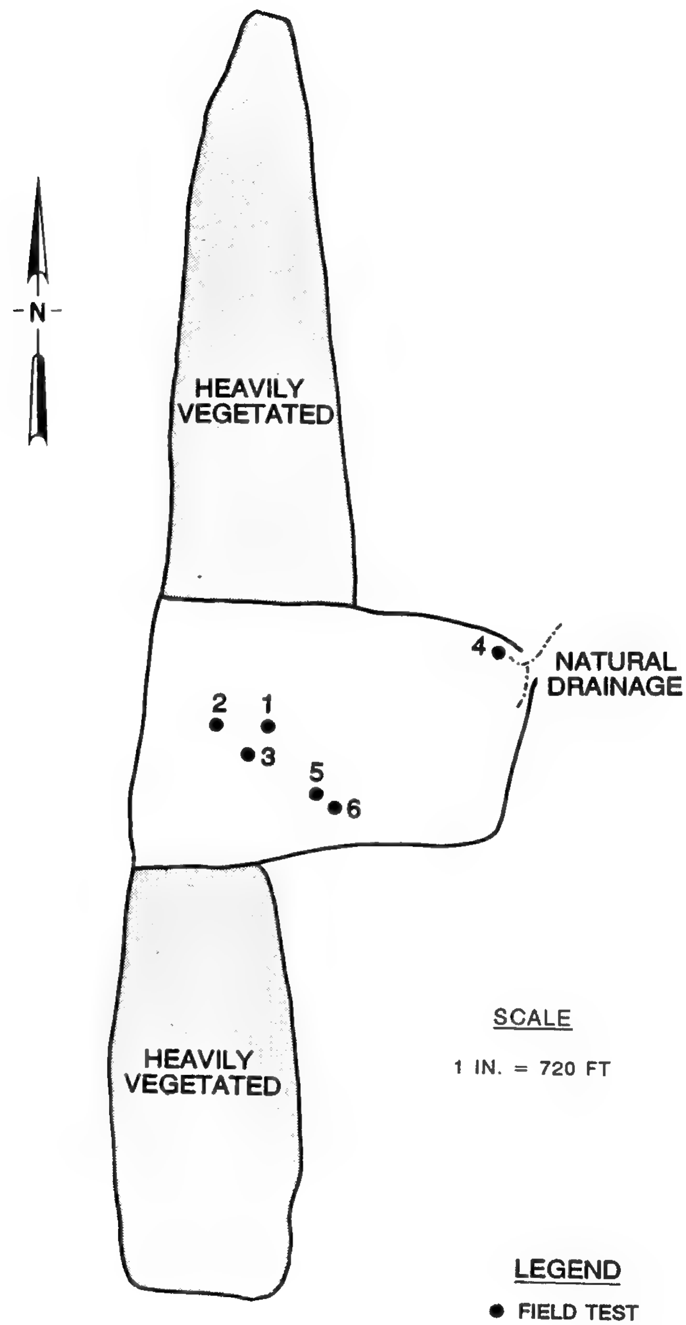

Figure 6. Artificial Island dredged material disposal area, Salem, NJ

Figure 7. GEMCO vehicle with Dondi ditcher being lowered into position for trenching

trenching passes were made. The second pass deepened the trench created by the first pass. During operation, the vehicle created ruts approximately 3 ft deep. In test 4, the vehicle was ditching in wet, relatively soft material. Because of adhesion and caking of this material between the tire treads, the vehicle lost traction and had to be assisted by the bulldozer; therefore, no time data were collected. The bulldozer is used primarily for earthmoving operations and vegetation removal, but its secondary use is assisting any vehicle which becomes immobilized.

Comparing the VCI_1 of 9 and the VCI_{50} of 23 with the RCI of the various test locations indicates that the vehicle should be able to make one pass across the Artificial Island site with little or no problem. However, mobility problems may occur if multiple passes were made in many areas.

Savannah District Field Evaluations

Equipment evaluations were conducted in the Savannah District's Disposal Area 12 (Figure 8) April 21-23, 1987. This site is located north of Savannah

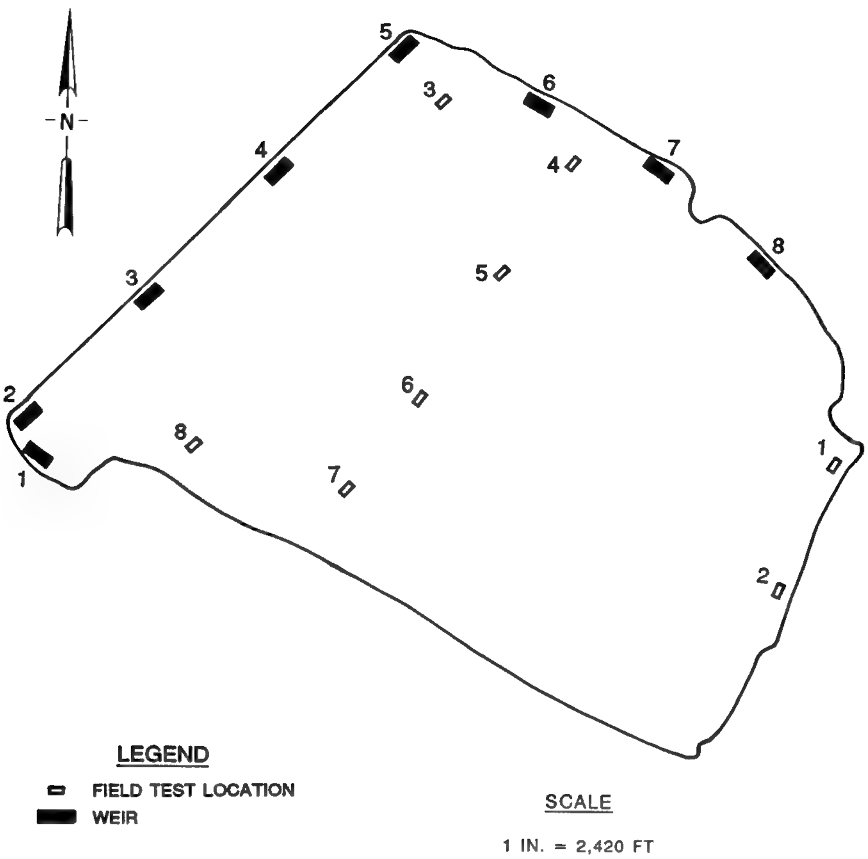

Figure 8. Disposal Area 12, Savannah, GA

adjacent to the Back River. Disposal Area 12 is one of several individual disposal sites (cells) located within one large diked containment area which is approximately 1 mile wide by 2 miles long, with the long axis being parallel to the Back River. Weirs were located along the north and west dikes at approximately 2,000-ft intervals. Fine-grained materials (mainly clays) are the prevalent material contained in these sites, although some sands and silts are present.

The equipment used at the Savannah District site was a GEMCO GT-150 and it pulled a Dondi 75 ditcher. This equipment is owned and operated by the Chatham County Department of Mosquito Control, the organization that routinely trenches disposal areas for the Savannah District. As shown in Figure 9, the vehicle can cross old trenches as necessary. The vehicle has been extensively modified to reduce the number of breakdowns previously experienced. The horsepower has been increased from 150 to about 175 by installing fuel injectors in the engine. The axles on the vehicle were upgraded by installing

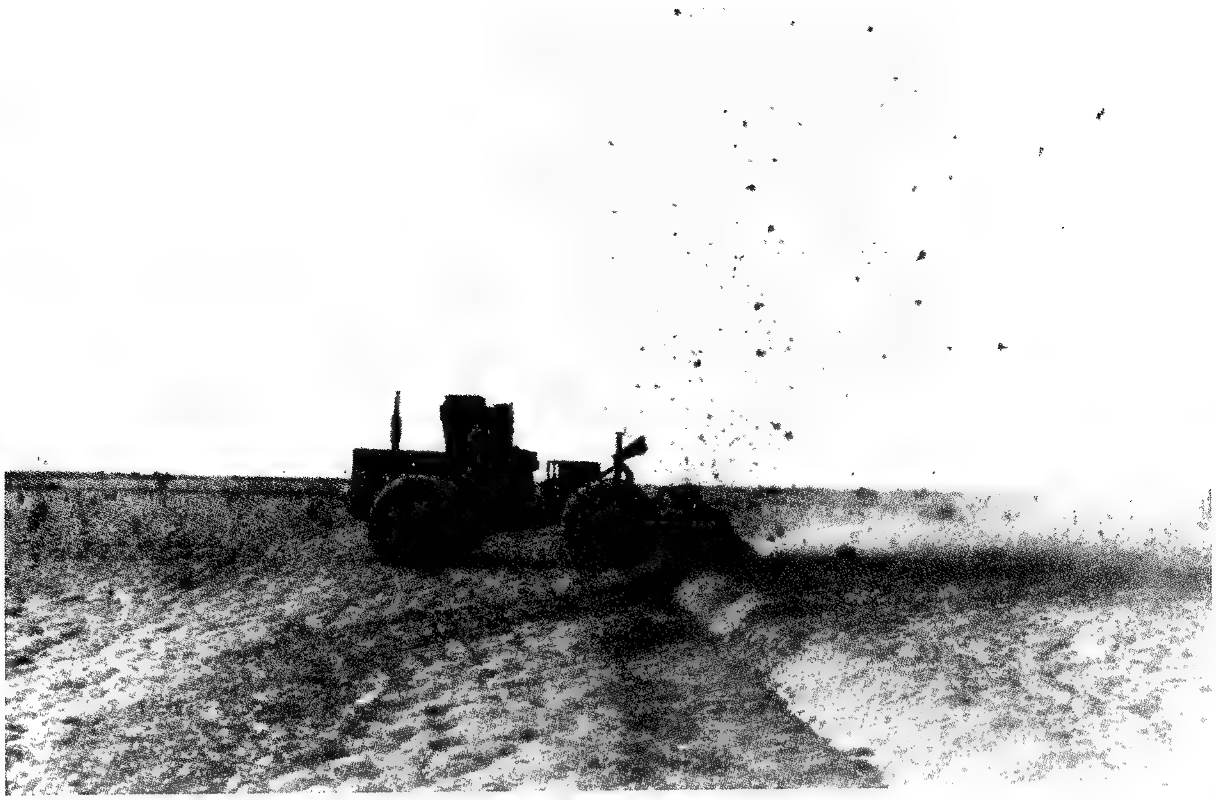

Figure 9. GEMCO vehicle crossing old ditch while trenching

Rockwell differentials. All hydraulic and oil hoses and coolers were replaced by larger and more efficient ones.

The top 6 in. of material in Disposal Area 12 consisted of a hard baked crust. The material from 6 to 18 in. was somewhat softer; at about 18 in., the material was very soft and had the consistency of axle grease. Field evaluations were conducted at eight locations in Disposal Area 12. The vehicle became immobilized at the eighth site, so no performance data were collected there. At some of the test locations the crust was so hard that a remolding index of 300+ was recorded (Table 4).

At all test sites except site 8, the vehicle was timed to provide performance information. Testing at site 8 was conducted after the vehicle became immobilized so that the RCI could be calculated for comparison to the VCI. Data collected at this site proves that a vehicle cannot operate on a site where the VCI is greater than the RCI. Comparison of the VCI_1 of 7 and the VCI_{50} of 18 with the soil's RCI indicates that at most locations within Disposal Area 12 the vehicle should be able to operate (either single or multiple passes) without problems, as long as the surface crust remains intact.

In some areas, the ability of the 6- to 12-in. layer of soil to support the equipment is questionable for even a single pass.

Vehicle Performance Comparison

All vehicles evaluated in this study were able to perform successfully when adequate crust was present, but none were mobile during the entire critical period between fluid and solid phases of dredged material. These rubber-tired, low-ground-pressure vehicles were able to operate at the dredged material disposal sites earlier than most conventional equipment (Figure 10). It should be noted that some low-ground-pressure tracked vehicles were not only mobile in the areas where the rubber-tired vehicles had mobility problems, but were used to tow immobilized equipment. The greatest problem with immobilization of either the ARDCO or the GEMCO seems to occur when the vehicle breaks

Figure 10. Corps of Engineers 4x4 vehicle immobilized where GEMCO pulling ditcher had no problem; note GEMCO treadmarks beside vehicle

through the hardened crust and the soft material below cakes between the tire treads causing a loss of traction.

The production rates for trenching varied by test site, but were relatively consistent among CE Districts. Production rates in both linear feet of ditch created per hour and cubic feet of material moved per hour are summarized in Table 5. From these data, the ARDCO and the GEMCO vehicles seem to have similar production rates. On the average, approximately 2,200 ft of trench can be created per hour and about 9,400 cu ft of material can be moved per hour.

Conclusions

The recently developed rubber-tired low-ground-pressure vehicles performed successfully in dredged material containment areas when sufficient drying had occurred to provide adequate soil support for the vehicle. The equipment could not perform trenching operations throughout the entire critical time period as dredged material changes from the fluid stage to a material sufficiently crusted to support conventional equipment. The equipment was able to begin trenching earlier than most conventional equipment, thus shortening the time during which the site is inaccessible. Based upon comparison of actual field performance and performance predictions made using field performance, the existing guidance and predictive techniques for determining equipment mobility in dredged material containment areas appears to be applicable to the new equipment. Therefore, no revision or modification of the guidance is necessary at this time.

Table 1

Triple Barrel Soil Data

Test No.*	S	Soil Evaluation: Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	36	24	12	21	0.94	0.54	0.59	23	6	12
2	37	22	13	20	0.80	0.81	0.70	22	13	20
3	40	31	13	19	0.74	0.80	0.68	23	13	19
4	67	59	30	28	0.81	0.67	0.40	48	20	11
5	69	69	32	21	0.94	0.88	0.67	62	28	16
6	48	37	16	18	--	0.85	0.54	--	14	15
8	33	22	14	21	0.74	0.58	0.69	16	8	14
9	32	24	13	19	0.63	0.66	0.53	15	9	10
10	32	24	13	19	0.63	0.66	0.53	15	9	10
11	33	24	13	25	0.65	0.51	0.47	16	7	12

* Location of tests shown in Figure 2.
Note: S = surface.

Table 2

Craney Island Soil Data

Test No.*	S	Soil Evaluation: Cone Index (CI) 0-6"	6-12"	12-18"	Remolding Index (RI) 0-6"	6-12"	12-18"	Rating Cone Index (RCI) 0-6"	6-12"	12-18"
1	32	47	36	38	0.58	0.61	0.65	27	22	25
2	33	37	68	82	0.72	0.62	0.56	26	42	46
3	40	54	68	59	0.46	0.65	0.50	25	44	30

* Location of tests shown in Figure 4.
Note: S = surface.

Table 3

Artificial Island Soil Data

Test No.*	S	Cone Index (CI) 0-6"	Cone Index (CI) 6-12"	Cone Index (CI) 12-18"	Remolding Index (RI) 0-6"	Remolding Index (RI) 6-12"	Remolding Index (RI) 12-18"	Rating Cone Index (RCI) 0-6"	Rating Cone Index (RCI) 6-12"	Rating Cone Index (RCI) 12-18"
1	64	39	55	56	0.58	0.40	0.36	23	22	20
2	43	50	70	79	0.68	0.56	0.54	34	34	43
3	20	28	43	74	0.56	0.50	0.54	16	16	40
4	22	24	84	28	0.68	0.54	0.80	16	16	23
5	44	67	75	74	0.73	0.58	0.71	49	44	23
6	--	86	--	--	0.75	--	--	64	--	--**

* Location of tests shown in Figure 6.
** On test 6 only the RCI from the 0- to 6-in. layer was obtainable due to the *Phragmites* roots.
Note: S = surface.

Table 4

Savannah District Soil Data, Disposal Area 12

Test No.*	S	Cone Index (CI) 0-6"	Cone Index (CI) 6-12"	Cone Index (CI) 12-18"	Remolding Index (RI) 0-6"	Remolding Index (RI) 6-12"	Remolding Index (RI) 12-18"	Rating Cone Index (RCI) 0-6"	Rating Cone Index (RCI) 6-12"	Rating Cone Index (RCI) 12-18"
1	30	34	39	43	0.83	0.67	0.65	28	26	28
2	33	41	38	30	300+	0.77	0.63	300+	29	19
3	30	32	15	12	0.88	0.61	0.43	28	9	5
4	41	34	15	27	300+	0.60	0.40	300+	9	11
5	26	29	27	48	300+	0.66	0.58	300+	18	28
6	20	33	45	46	300+	0.65	0.68	300+	29	31
7	24	32	43	61	300+	0.80	0.39	300+	34	24
8	44	21	22	18	0.28	0.37	0.49	6	8	9

* Location of tests shown in Figure 5.
Note: S = surface.

Table 5

Vehicle Production

Site	Test No.	Minutes per 100 ft	Linear Ditching ft/hr	Material Removed cu ft/hr
Mobile	1	1.16	2,586	8,100
	2	1.07	2,804	8,781
	3	1.07	2,804	8,781
	4	1.16	2,586	10,014
	5	1.28	2,344	9,075
	6	1.24	2,419	9,368
	8	1.50	2,000	7,744
	9	1.20	2,500	9,680
	10	1.20	2,500	9,680
	11	1.57	1,911	9,806
Norfolk	1	4.25	1,412	4,015
	2	4.33	1,386	3,941
	3	4.00	1,500	4,266
Philadelphia	1	2.25	2,667	11,000
	2	2.00	3,000	11,250
	3	2.08	2,885	10,817
	5*	3.33	1,802	8,014
	6	3.77	1,591	11,273
Savannah	1	2.50	1,200	8,666
	2	1.44	2,083	15,046
	3	1.50	2,000	14,444
	4	1.54	1,948	8,778
	5	1.16	2,586	11,653
	6	1.75	1,715	7,724
	7	1.10	2,727	12,289
	8**	--	--	--

* During test 4 the vehicle became immobilized, and had to be assisted by the bulldozer; no times recorded. Tests 5 and 6 both were dual passes to deepen the ditch; therefore, the performance factors are lower than tests 1, 2, and 3.

** Vehicle became immobilized; no times recorded.

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